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THE CREATION AND ANALYSIS OF THE COMPUTER NETWORK MODEL BASED ON ECOLOGY

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Currently, the ecology was used in the network security by many researchers. But the correspondence between the network and the ecology systems were studied by few researchers which limited the development of cross fields between network and ecology. Due to the rapid development, the structure of computer network is increasingly complicated. The traditional static network model is difficult to characterize the topological properties and dynamic development of computer network. So, based on ecological theory, this paper proposes an ecological computer network model, namely Monomer-Multimer computer network model. The Monomer-Multimer computer network model can not only simulate the computer network, but also describe the dynamic development of computer network from the view of eco-development. In addition, this model is easier to describe the information dissemination mechanism of the computer network. A variety of virus propagation models and anti-virus strategies can also apply to this model. In this paper, the completeness of the Monomer-Multimer computer network model is proven by the complex network and the theory of model completeness. The feasibility of the Monomer-Multimer computer network model is also proven by the Agent.

Keywords: Complex network, Ecology, Completeness, Agent, Monomer-Multimer computer network mode

1. Introduction

In the 1970s, researchers applied biological knowledge to the field of computer for the first time. Holland from the United States put forward the classifier theory and believed that the biological immune system is a classifier, which can distinguish between "self" and "non self" and can distinguish between harmful and harmless in "self" and "non-self"[1]. Since Jon T. meek, Edwin S et al put forward the concept of WAN network ecology in 1998, Internet Ecology and information ecology have emerged. Network ecology has gradually become an important research field [2-5]. Computer network is a complex network. In the complex models, scale-free network model provides an effective method to study the evolution and ecological characteristics of the network [6-9].

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Computer network is a typical scale-free complex network, which conforms to the power-law distribution with power-law index of 2 ~ 3 [10]. Fan et al established a copy model of biological network [11]. Zhang studied the evolution of the Internet [12]. Barabási believed that the response of Internet for the attacks can be predicted by the methods of complex network [13]. These results focus on the local characteristics of network ecology [14]. However, there is still a blind spot in establishing a complete network ecological model.

In recent years, complex networks, propagation dynamics and artificial immunity have been used in the field of network security by the researchers [15-18]. However, few researchers have made strict mathematical analysis on the corresponding relationship between computer network and ecosystem. Moreover, it is difficult to describe the topological characteristics of computer networks from the perspective of dynamic development. In addition, although these achievements have done a lot of research on the ecological characteristics of the network, they have not given the ecological model for the whole computer network. Therefore, a complete ecological network model of computer network, Monomer-Multimer computer network model, is proposed. Through the research on the description of network ecology, the paper gives the definition of basic elements of ecological network, model construction rules and information dissemination mechanism. It lays a foundation for the in-depth application of ecological theory in the research of computer network model. The construction rules of the model make its distribution finally tend to the power-law distribution with exponent 2~3, which can simulate the computer network topology. In addition, this model studies the corresponding relationship between computer network and ecosystem in detail and makes a strict mathematical analysis of this relationship to verify the completeness of the model. On this basis, the information dissemination mechanism of the computer network on this model is simulated. The results show that the model can simulate the real computer network very well.

2. Monomer-Multimer computer network model and related definitions

The methods of ecology used to study the computer network need to address the issues about modeling, the mapping of the concept and the key elements between the ecology and the network, and the mapping relationship among the problem domain of the model. At present, researchers have made a lot of achievements in solving problems in the computer field by using ecological methods. However, few researchers have studied the corresponding relationship between network and ecosystem, which limits the development of the cross field of network and ecology. Additionally, these achievements only solved one aspect of the computer network problem by the ecological methods, for example, the research of transmission of the virus and anti-virus strategy on the computer network. No researchers have given an ecological model about the overall computer network in the scope of author's knowledge.

Therefore, this paper proposes a computer network model, Monomer-Multimer computer network model. The model can not only accord with the real computer network in topology, but also accord with the real computer network in mapping relationship. In addition, the model is easier to describe the information transmission mechanism of computer network, and various virus transmission models and anti-virus strategies are also suitable for the model. Monomer-Multimer computer network model consists of monomer, Multimer and information flow. The information flow is the energy of the model. And the model will be not work if there is no exchange of information. The information in this model is divided into security information and hazard information. When the monomer receives the hazard information and its security policy cannot restrain such violations effectively, the monomer may lesion.

Relevant elements of the model are defined as follows:

Definition 1: Monomer is an entity with information processing ability in the network, which can interact with other monomers. The monomer is expressed as $g_i = \{SI_i, Sp_i, r, e, p\}$, where SI_i is the identifier of the monomer; Sp_i is the security policy of the monomer; r indicates the links between two monomers, if $r(g_i, g_j)$ and $r(g_j, g_k)$ then $r(g_i, g_k)$; e denotes the rules that the monomer goes into the model; p represents the infection exponent of the monomer, if $p = 0$ the monomer is healthy, and if $p > 0$ the monomer is sick; the infection exponent of the monomer will plus 1 when the monomer is attacked.

Definition 2: security policy. The security policy of the monomer is a finite set: $Sp_i = \{Sp_{ij} \mid 1 \le j \le n\}$, where $Sp_{ij} = \{Sig_j, Sp_j^{msg}, tf\}$; Sig_j is the signature of the security policy corresponding to the hazard information; Sp_j^{msg} is the detailed information about the measures of the security policy; tf is a Boolean variable whose value is 0 or 1. If the security policy is failure to against the hazard information, then $tf = 0$. The original security strategy will be genetic variation to extract the more suitable strategy which can against the hazard information to cover the original strategy. If the security policy can resist the hazard information, $tf = 1$.

Definition 3: Multimer is a set of monomers which linked each other under the certain rules: $G = (E, g, R)$, where E represents the rules set; $g = \{g_i \mid 1 \le i \le n\}$

represents the set of monomers under the rules; R represents the links which were emerged among the links of the monomers, and the links among the Multimers, that is $R(G_a, G_b) = R(r_{G_a}(g_i, g_j), r_{G_b}(g_i, g_j))$

Definition 4: The information flow is the energy of the model as well as the foundation of the model's normal operation. The information in this model is divided into security information and hazard information. When the monomer received the hazard information and the security policy cannot restrain such violations effectively, the monomer may lesion. Information is expressed as $Msg = (Msg_{security}, Msg_{danger})$, where $Msg_{security}$ represents the security information which maintain the normal operation of the model, and Msg_{danger} represents the information which has the potential security risk and may be harmful for the normal operation of the model, $Msg_{danger} = \{Ide, Sig\}$, Ide is the identifier of the hazard information, Sig is the signature of the hazard information.

3. The construction of the Monomer-Multimer computer network model

This section describes the construction process of the model and verifies that the model satisfies the topology of real computer network.

3.1 The construction of the model

The creation of the Multimer: create the Multimer by definition 3 in which the creation rules E of the Multimer is: generating a Multimer with m_0 monomers and n edges according to the creation rules of BA scale-free network model.

Create m Multimers and making the m Multimers contact each other randomly. Then, in the same interval, the creation of the model is as follows:

Create a monomer and add it into a Multimer which has existed in the model. According to the characteristics of BA scale-free network, the connection status (degree) between nodes has serious uneven distribution. In the network, a few nodes called hub points have extremely many connections, while most nodes have only a small number of connections. Therefore, when the monomer is added to the Multimers, the preferred probability is used to preferentially connect with the monomer which has large node degree.

First, select a Multimer G_i randomly and then select m_1 monomers in this Multimer to contact with the new monomer according to the preferred probability as follows.

$$\prod(k_i) = \frac{k_i}{\sum j \in G_i \, k_j}, \qquad (1)$$

k_i represents the degree of the ith node.

Select m_2 pairs of monomers in a selected Multimer, making the two monomers in all pairs contact each other. The selection processes for each pairs of monomers are the same. First, select a Multimer randomly and then select a monomer randomly in this Multimer, after that, the other monomer is selected by the preferential probability (1).

Maintaining the size of the system unchanged, select m_3 pairs of monomers which contract with each other in a selected Multimer and abolish the links between these monomers. The selection process for each pair is the same: one of the monomer is selected randomly, and the other one is selected by the probability of anti-preferred as follows.

$$\prod{}_*(k_i) = \frac{1-\prod(k_i)}{N_{G_i}(t)-1}, \qquad (2)$$

Where, $N_{G_i}(t)$ are the number of monomers in the Multimer G_i, $(N_{G_i}(t)-1)^{-1}$ is the standardized coefficient of the probability which making $\sum_i \prod_*(k_i) = 1$. The probability of anti-preferred which is consistent with the real computer network is more reasonable for remove the connections.

Select m_4 pairs of Multimers, making the two Multimers in every pair contact to each other. Each pair of the selection process for the Multimers is: first select a Multimer randomly and select a monomer in it by equation (1), and then select the other Multimer randomly and select a monomer in it by (1) too, finally making the two monomers contact to each other.

Select m_5 pairs of Multimers which were contacted to each other, and then, cut off the connection between each pair of Multimers. The selection process of each pair is: first select a Multimer randomly, then select the other one by equaption (2) in the Multimers who was contact with the first one.

Hypothesis 1: System parameters satisfy the conditions as follows: $m, m_1, m_2, m_3, m_4, m_5$ are integers, $m_1 + m_2 > 2(m_3 + m_5)$. The monomers are not allowed to self-connect and re-connect in the generated course of the whole system.

3.2 The degree distribution of the Monomer-Multimer computer network model

According to the creation rules of the model, after t intervals, the total connectivity of each Multimer in the system averagely is:

$$\sum_{j \in G_i} k_j = \frac{2t(m_1 + m_2 - m_3 + m_4 - m_5)}{m}, \tag{3}$$

The number of the monomers in the Multimer G_i averagely is:

$$N_{G_i}(t) = m_0 + \frac{t}{m} \approx \frac{t}{m}, \text{ for the large t} \tag{4}$$

Use the mean field theory to analyze the degree distribution of the monomer i in the Multimer G_i according to the creation rules of the model. The core idea of the mean field theory is that the overall interaction effect is equivalent to a “mean field”, not to calculate the interaction of local and different everywhere. The derivation is as follows:

Add a new monomer into a Multimer.

$$\frac{\partial k_i}{\partial t} = \frac{m_1}{m} \times \frac{k_i}{\sum_{j \in G_i} k_j}, \tag{5}$$

The right-hand side of the equation corresponds to the random selection of the Multimer and the preferential selection of the monomer. The new monomer contact with the other m_1 monomers that is equivalent to create m_1 edges, so the coefficient is m_1.

Select m_2 pairs of monomers in a selected Multimer, making the two monomers in every pairs contact to each other. The process is equivalent to add m_2 edges in this Multimer.

$$\frac{\partial k_i}{\partial t} = \frac{m_2}{m}\left[\frac{1}{N_{G_i}(t)} + \left(1 - \frac{1}{N_{G_i}(t)}\right)\frac{k_i}{\sum_{j \in G_i} k_j}\right], \tag{6}$$

The first item in the brackets represents the selection of the monomer i in a Multimer, the second item represents the preferential selection of the other monomer in the same Multimer.

Select m_3 pairs of monomers in a selected Multimer and abolish the links between these monomers. That is equivalent to delete m_3 edges in the Multimer.

$$\frac{\partial k_i}{\partial t} = -\frac{m_3}{m}[\frac{1}{N_{G_i}(t)} + (1-\frac{1}{N_{G_i}(t)})\frac{1}{N_{G_i}(t)-1}(1-\frac{k_i}{\sum_{j\in G_i} k_j})] , \quad (7)$$

The connectivity of the monomer is affected by two respects, one is the end that select randomly, the other one is the end that select by equation (2).

Select m_4 pairs of Multimers, making the two Multimers in every pairs contact each other. That is equivalent to add m_4 edges among the Multimers.

$$\frac{\partial k_i}{\partial t} = m_4[\frac{2}{m}\times\frac{k_i}{\sum_{j\in G_i} k_j} - \frac{1}{m^2}\frac{k_i}{\sum_{j\in G_i} k_j}] , \quad (8)$$

Select m_5 pairs of Multimers which was contacted to each other, and then cut off the connection of each pair. That is equivalent to delete m_5 edges among the Multimers.

$$\frac{\partial k_i}{\partial t} = -m_5[\frac{2}{m}\times\frac{1-\prod(k_i)}{N_{G_i}(t)-1} - \frac{1}{m^2}\times\frac{1-\prod(k_i)}{N_{G_i}(t)-1}] , \quad (9)$$

By combining equations (3) ~ (9) together, and making $R = 2(m_1 + m_2 - m_3 + m_4 - m_5)$, for the large t, one has:

$$\frac{\partial k_i}{\partial t} \approx \frac{m_1}{m}\times k_i \times \frac{m}{Rt} + \frac{m_2}{m}\left(\frac{m}{t} + k_i \times \frac{m}{Rt}\right) - \frac{m_3}{m}\left[\frac{m}{t} + \frac{m}{t}\left(1 - k_i \times \frac{m}{Rt}\right)\right] + m_4\left(\frac{2}{m}\times k_i \times \frac{m}{Rt} - \frac{1}{m^2}\times k_i \times \frac{m}{Rt}\right) - m_5 \times\left(2 - \frac{1}{m}\right)\times\frac{1}{t}$$

$$= \frac{m_1 k_i}{Rt} + \frac{m_2}{t} + \frac{m_2 k_i}{Rt} - \frac{2m_3}{t} + \frac{2m_4 k_i}{Rt} - \frac{m_4 k_i}{mRt} - \frac{(2m-1)m_5}{mt}$$

$$= \left(\frac{m_1}{R} + \frac{m_2}{R} + \frac{2m_4}{R} - \frac{m_4}{mR}\right)\frac{k_i}{t} + \left[m_2 - 2m_3 - \frac{(2m-1)m_5}{m}\right]\frac{1}{t}$$

Define $A = \frac{m_1}{R} + \frac{m_2}{R} + \frac{2m_4}{R} - \frac{m_4}{mR}$, $B = m_2 - 2m_3 - \frac{(2m-1)m_5}{m}$, then the above equation can be expressed as:

$$\frac{\partial k_i}{\partial t} = A\frac{k_i}{t} + B\frac{1}{t}, \tag{10}$$

Solve this linear differential equation of first order by the initial condition $k_i(t_i) = m_1$:

$$k_i(t) = -\frac{B}{A} + \left(m_1 + \frac{B}{A}\right)\left(\frac{t}{t_i}\right)^A, \tag{11}$$

Get the probability of the nodes $k_i < k$ by equation (11):

$$P(k_i(t) < k) = P\left[k_i > \left(\frac{m_1 + \frac{B}{A}}{k + \frac{B}{A}}\right)^{\frac{1}{A}} t\right], \tag{12}$$

Since the nodes are added in the average time interval, namely, t_i follows the uniform distribution in the interval $(0, mm_0 + t)$. So substituting $P(t_i) = \frac{1}{mm_0 + t}$ into (12) yields:

$$P(k_i(t) < k) = P\left[k_i > \left(\frac{m_1 + \frac{B}{A}}{k + \frac{B}{A}}\right)^{\frac{1}{A}} t\right] = 1 - \frac{1}{mm_0 + t}\left(\frac{m_1 + \frac{B}{A}}{k + \frac{B}{A}}\right)^{\frac{1}{A}} t, \tag{13}$$

So, the degree distribution of the model is:

$$P(k) = \frac{\partial P(k_i(t) < k)}{\partial k} = \frac{t}{A(mm_0 + t)} \times (m_1 + \frac{B}{A})^{\frac{1}{A}} (k + \frac{B}{A})^{-(1+\frac{1}{A})}, \tag{14}$$

The scaling exponent $\gamma = 1 + \frac{1}{A}$. Substituting $A = \frac{m_1}{R} + \frac{m_2}{R} + \frac{2m_4}{R} - \frac{m_4}{mR}$, $R = 2(m_1 + m_2 - m_3 + m_4 - m_5)$ into γ yields:

$$\gamma = 1 + \frac{1}{A} = 1 + \frac{1}{\frac{m_1}{R} + \frac{m_2}{R} + \frac{2m_4}{R} - \frac{m_4}{mR}} = 2 + \frac{mm_1 + mm_2 - 2mm_3 - 2mm_5 + m_4}{mm_1 + mm_2 + 2mm_4 - m_4}$$

Next, analyze the range of the scaling exponent γ :

By the condition: $m, m_1, m_2, m_3, m_4, m_5 \geq 1$, are integers, one obtains:

$$m_1 + m_2 + 2m_4 > m_4$$

$$\Rightarrow m(m_1 + m_2 + 2m_4) > m_4$$

$$\Rightarrow mm_1 + mm_2 + 2mm_4 - m_4 > 0$$

And by the condition $m_1 + m_2 > 2(m_3 + m_5)$, it is:

$$m(m_1 + m_2) > 2m(m_3 + m_5)$$

$$\Rightarrow mm_1 + mm_2 - 2mm_3 - 2mm_5 > 0$$

$$\Rightarrow mm_1 + mm_2 - 2mm_3 - 2mm_5 + m_4 > 0$$

So, $\frac{mm_1 + mm_2 - 2mm_3 - 2mm_5 + m_4}{mm_1 + mm_2 + 2mm_4 - m_4} > 0$.

$$\gamma = 2 + \frac{mm_1 + mm_2 - 2mm_3 - 2mm_5 + m_4}{mm_1 + mm_2 + 2mm_4 - m_4}$$

$$= 2 + \frac{(mm_1 + mm_2 + 2mm_4 - m_4) - 2mm_4 - 2mm_3 - 2mm_5 + 2m_4}{mm_1 + mm_2 + 2mm_4 - m_4}$$

By the condition: $m, m_1, m_2, m_3, m_4, m_5 \geq 1$, are integers, so:

$$m_4 < m_4 + m_3 + m_5 < m(m_4 + m_3 + m_5)$$

$$\Rightarrow 2m_4 - 2mm_4 - 2mm_3 - 2mm_5 = 2m_4 - 2m(m_3 + m_4 + m_5) < 0$$

So, $\frac{(mm_1 + mm_2 + 2mm_4 - m_4) - 2mm_4 - 2mm_3 - 2mm_5 + 2m_4}{mm_1 + mm_2 + 2mm_4 - m_4} < 1$.

In conclusion: $0 < \frac{mm_1 + mm_2 - 2mm_3 - 2mm_5 + m_4}{mm_1 + mm_2 + 2mm_4 - m_4} < 1$

Thus, $2 < \gamma < 3$. When $m_3 = m_4 = m_5 = 0$, the scaling exponent $\gamma = 3$, at that time the model degenerate to the BA scale-free model.

The power-law distribution curve of the BA model and the Monomer-Multimer computer network model (γ=2.1613: $m_1 = 3, m_2 = 4, m_3 = 2, m_4 = 2, m_5 = 1, m = 3$; γ=2.6963 $m_1 = 8, m_2 = 3,$ $m_3 = 1, m_4 = 2, m_5 = 1, m = 1$) have drawn in Fig. 1.

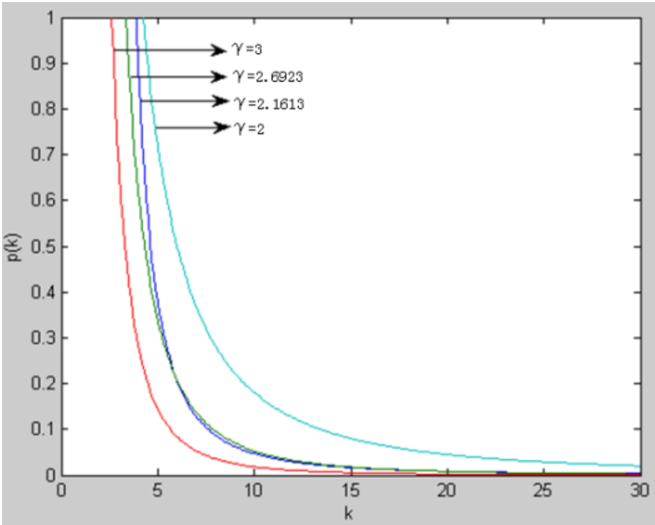


Fig. 1. Power-law distribution curves of the BA model and the Monomer-Multimer computer network model

The Monomer-Multimer computer network model tends to the power-law distribution with exponent $2<\gamma<3$ under the construction rules. The power-law exponent varied from 2 and 3 through adjust the parameters. Therefore, the model is consistent with the topological distribution of computer network very much, which proves that the model can simulate the computer network accurately.

4. Proof of completeness for the Monomer-Multimer computer network model

The previous section shows that the model tends to the power-law distribution and can describe the computer network accurately. This section proves the completeness of the model from the view of completeness of the axiom system to further demonstrate the superiority of the model.

From the view of completeness of the axiom system, the completeness of the map between the model and the computer network is proved. Completeness of the axiom system is defined as follows:

Theorem 1: if the objects in the two model Ω_1 and Ω_2 of the axiom system Σ can establish one to one mapping, and there are the same relationship between the corresponding objects, then in the axiom system the two models Ω_1 and Ω_2 are isomorphism [19].

Theorem 2: if all the models in the axiom system Σ are isomorphic, then Σ is a complete axiom system [19].

The completeness of the Monomer-Multimer computer network model will be proved by the Theorem 1 and Theorem 2. First, the isomorphism between the Monomer in the model and the node in the network will be proved. Then, the isomorphism between the Multimer in the model and the Local Area Network (LAN) in the computer network will be proved.

Hypothesis 2: Q represents a LAN in the real computer network, $Q = < q, l >$, $q = \{q_i \mid 1 \le i \le n\}$,where q_i represent the nodes in the network. The connection between the nodes in the network is expressed as l, including physical connection l_P and logical connection l_L. All the connections constitute a set: $L = \{l_P(q_a, q_b), l_L(q_a, q_b) \mid q_a, q_b \in Q\}$. The connections in the network have the nature of transfer: $\forall q_a, q_b, q_c \in Q$, if it has $l(q_a, q_b)$ and $l(q_b, q_c)$, then $l(q_a, q_c)$. The connection between the LAN is emerged by the connections among the network nodes.

4.1 Proof of isomorphism between the monomer and network node

(1) The network node (personal host) and the safety switching device both can configure the security policies by the basic principles of network security. Form the view of reality, each node accessed to the network has defense capabilities. Here, it assumes that the network is a secure network, in which each node equipped the security policy: $q_i \in \{Q_{sp} : \text{nodes configured security policy}\}$. A network node is a monomer from the definition of monomer. Namely, it exists the map $\phi : q_i \to g_i$ which is a surjection.

(2) Next the corresponding of the binary relationship between the two models are proved in this section, namely, it exists $\phi\left(l\left(q_i, q_j\right)\right) = r\left(\phi\left(q_i\right), \phi\left(q_j\right)\right) = r(g_i, g_j)$ for any two nodes in the network q_i and q_j.

From the basic definition of the network: $\forall q_i, q_j \in Q$ it has $l\left(q_i, q_j\right)$, namely, any two nodes in the network exist connection. The operation mechanism of the Monomer-Multimer computer network model shows that any two monomers can exchange the information through the transit of other monomer.

So, any two monomers in G_i have contact $r(g_i, g_j)$. There is a mapping $\phi: q_i \to g_i, q_j \to g_j$ from the proof of (1). Therefore, $\phi\left(l\left(q_i, q_j\right)\right) = r\left(\phi\left(q_i\right), \phi\left(q_j\right)\right) = r(g_i, g_j)$. Then, ϕ is a homomorphism mapping between the monomer and the network node.

(3) It can see from (1) that $\phi: q_i \to g_i, q_j \to g_j$ is a surjection. Next it proves that this mapping is a bijection, namely, if $q_i \neq q_j$ then $g_i \neq g_j$.

Supposed $q_i \neq q_j \Rightarrow g_i = g_j$ then $r_{g_i} = r_{g_j}$. It gets from (2): if $r_{g_i} = r_{g_j}$ then $l_{q_i} = l_{q_j}$, that is $q_i = q_j$, which is contradict for the suppose $q_i \neq q_j$. So if $q_i \neq q_j$ then $g_i \neq g_j$. Therefore, the mapping is a bijection.

From (1)(2)(3), it gets that ϕ is a bijection and the binary relations of any two element in Q satisfy $\phi\left(l\left(q_i, q_j\right)\right) = r\left(\phi\left(q_i\right), \phi\left(q_j\right)\right) = r\left(g_i, g_j\right)$. So ϕ is a isomorphism between monomer and network node.

4.2 Proof of isomorphism between Multimer and LAN

(1) The LAN is linked by the network nodes which was equipped with the security policy. The contract between LAN is emerged by the contract of network nodes, so there is a mapping $\varphi: Q_i \to G_i$. Because there is a one-to-one mapping between monomer and network node, then the mapping φ is a one-to-one mapping by the definition of Multimer and LAN.

(2) Next it proves the corresponding of the binary relations, that is $\varphi\left(L\left(Q_a, Q_b\right)\right) = R\left(\varphi\left(Q_a\right), \varphi\left(Q_b\right)\right) = R\left(G_a, G_b\right)$.

It has $L\left(Q_a, Q_b\right) = L\left(l_{Q_a}\left(q_i, q_j\right), l_{Q_b}\left(q_i, q_j\right)\right)$ in the reality network, and $R\left(G_a, G_b\right) = R\left(r_{G_a}\left(g_i, g_j\right), r_{G_b}\left(g_i, g_j\right)\right)$ in Multimer. The proof of above shows that there is a one-to-one mapping between the monomer and network node, furthermore there is a homomorphism mapping between them. $\phi: q_i \to g_i, q_j \to g_j \Rightarrow l_{Q_a}\left(q_i, q_j\right) \to r_{G_b}\left(g_i, g_j\right), l_{Q_b}\left(q_i, q_j\right) \to r_{G_b}\left(g_i, g_j\right)$, then it gets $\varphi\left(L\left(Q_a, Q_b\right)\right) = R\left(\varphi\left(Q_a\right), \varphi\left(Q_b\right)\right) = R\left(G_a, G_b\right)$.

In conclusion, the mapping φ is an isomorphism between the Multimer and LAN.

In summary, the monomer and Multimer in the model as well as the node and LAN in the computer network are isomorphism. So the model is completeness according to the completeness definition of the axiom system.

5. Simulation and verification of information dissemination mechanism

Section 3 and 4 has proved that the model can simulate the computer network very well on the topology by mathematical proof. This section simulates the information dissemination mechanism of the computer network using Monomer-Multimer computer network model to further verify the applicability of the model in the computer network.

5.1 Simulate of information dissemination about computer network

Information flow is the basis for the normal operation of the model. The model will not run without the flow of information. In this model, monomers exchange the information through the link, and any two monomers can exchange the information through the transit of other monomer. The model will work as Fig. 2. when the information flow exists.

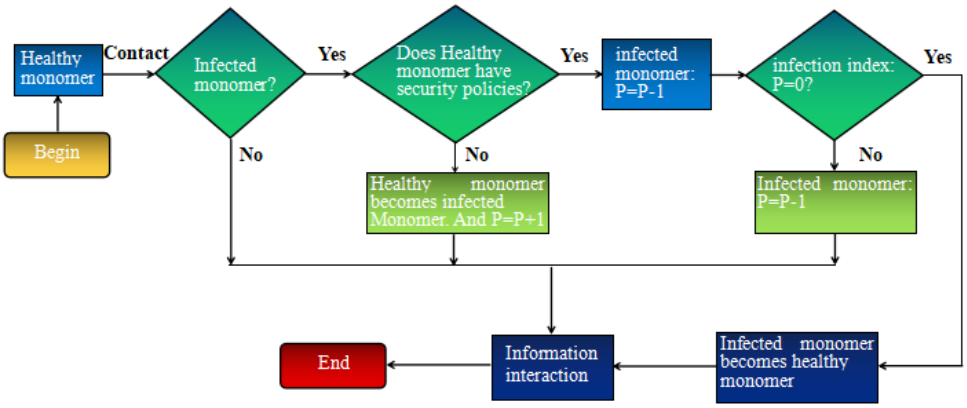


Fig. 2. Operation process of the Monomer-Multimer computer network model

Before a healthy monomer exchange the information with other monomers, it checks that whether the monomer has the hazard information or not. If the monomer carries the hazard information, then the healthy monomer examines its security policies. If there is a solution for the hazard information in the security policy, the infection index of the infected monomer will be reduced by 1. At this time, if the infection index of the infected monomer is equal to 0, the healthy monomer sends the safety policy to the infected monomer. The infected monomer becomes healthy monomer. If the infection index of the infected monomer is not equal to 0 at this time, the security policy will not be sent to the infected monomer, and the infected monomer is still infected. If there is no solution for this hazard information in the security policy, the infection index of the healthy monomer plus 1 becomes the infected monomer, and then the information is exchanged. If the monomer is healthy then exchange the information directly.

Before an infected monomer exchange the information with the other monomers, it checks that whether the monomer is a healthy one or not, if so, the same as above; if not, the infection index of both monomers adds 1.

5.2 Simulation

In this paper, the simulation experiment of the model is carried out by using Agent. In the experiment, the total amount of monomers was 10000 in the initial stage, in which the number of healthy monomers and infected monomers were H = 9950 and I = 50 respectively.

In the first case, some healthy monomers have health strategies for infected monomers. Fig. 3. shows the change of the number of two types of monomers over time. Fig. 4 (a) shows the morphology of two types of monomers in Multimer at the initial stage, in which green represents healthy monomers and red represents infected monomers. It can be seen from the figure that some monomers have been infected and become infected monomers. Fig. 4 (b) shows the morphology of two types of monomers when t = 10. It can be seen from the figure that only some healthy monomers have health strategies for infected monomers, so in the interaction, some healthy monomers become infected monomers. It can be seen from Fig. 3. that when t = 10, the number of infected monomers reaches the peak. Fig. 4. (c) shows the morphology of two types of monomers when t = 35. One can see that, with the spread of health strategies, all monomers eventually become healthy monomers.

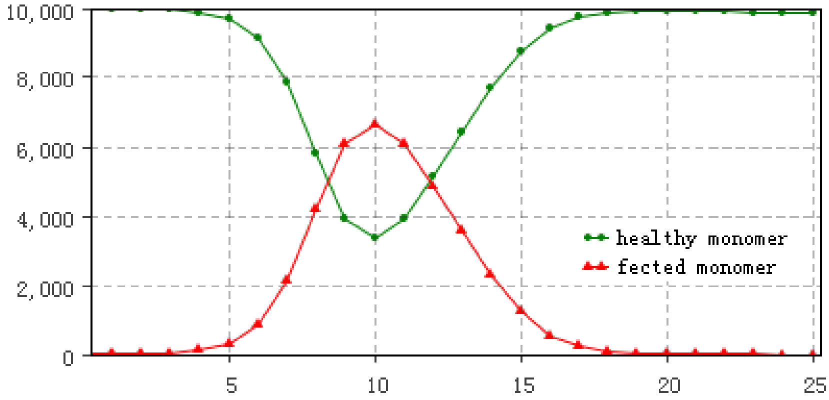
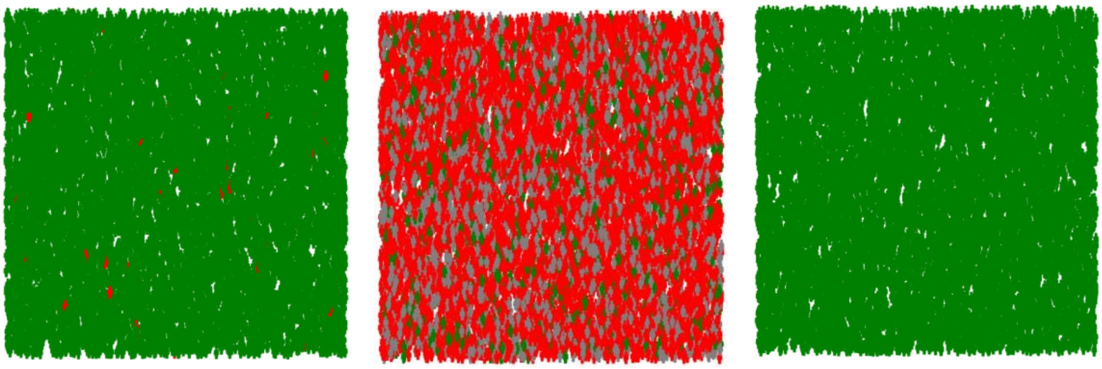


Fig. 3. the changes of the number about two type of monomers



t=0 t=10 t=25

(a) (b) (c)

Fig. 4. The healthy monomer has a security policy of infected monomer.

In the second case, there is no safety strategy for infected monomers in healthy monomers. Fig. 5 shows the change of the number of two types of monomers over time. Fig. 6 (a) shows the morphology of two types of monomers in the initial stage. As can be seen from Fig. 6 (b), some healthy monomers become infected monomers with the progress of interaction when t = 7. As shown in Fig. 6 (c), all monomers become infected monomers when t = 20.

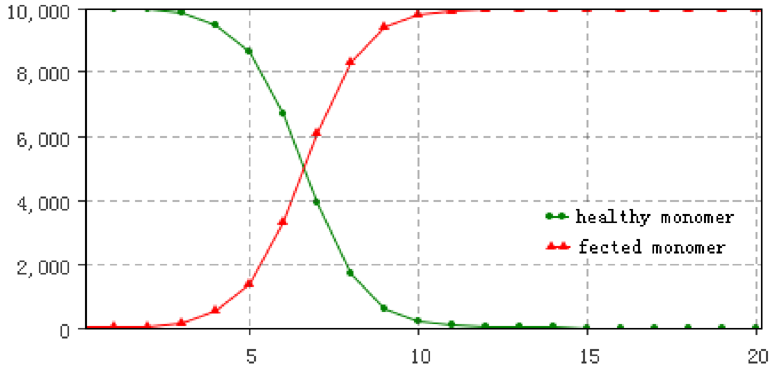
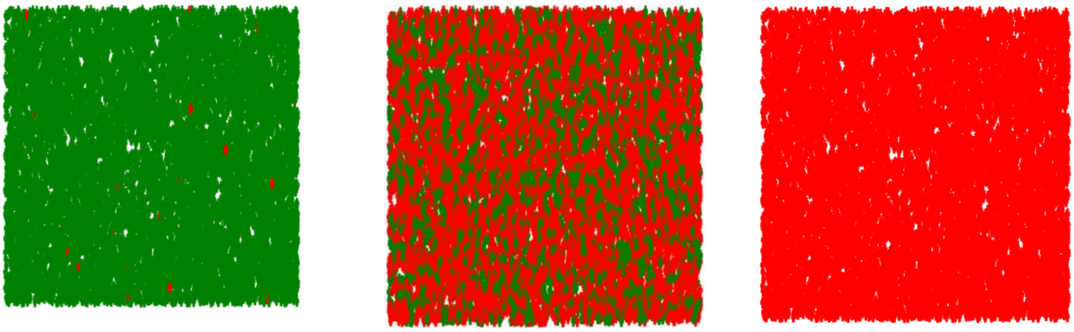


Fig. 5. the changes of the number about two type of monomers



t=0 (a)

t=7 (b)

t=20 (c)

Fig. 6. the healthy monomer doesn't have security policy of infected monomer.

5.3 Discussion

Simulation Analysis:

In simulation 1, some healthy monomers have health strategies for infected monomers. In BA scale-free network, the connection status (degree) between nodes has serious uneven distribution. A few hub nodes in the network have extremely many connections, and such nodes are more vulnerable to infection. Therefore, in the early stage of the experiment, the infection speed of infected monomers is particularly fast. When the number of infected monomers reaches a certain peak, it will decline rapidly because some healthy monomers contain infected monomers. In simulation 2, there is no health strategy for infected monomers in healthy monomers. Finally, all monomers become infected monomers with the progress of interaction. By observing the peak time of infected monomers in Fig. 3 and Fig. 5, it is not difficult to find that when there is no health strategy, the speed of infection increases significantly with the increase of the number of infected monomers.

Through the above two simulations, the proposed model can well describe the state of the network in danger under the above two situations. In a LAN, when all hosts do not have a virus security policy, with the interaction of information, all hosts in the LAN will be infected. Once the security policy of virus appears in the LAN, the virus will disappear from the network with the interaction of information.

Model comparison:

The traditional computer network models divide the computer network vertically from the perspective of layering, according to the transmission process of information. It cannot describe the dynamic development of computer network. The Monomer-Multimer computer network model analyzes the transmission process of computer network information from a horizontal perspective. It can better describe the dynamic development of computer network and help to study the transmission characteristics of computer virus and the distribution of anti-virus strategy. In the Monomer-Multimer computer network model, each monomer is equipped with security policies. The monomers can learn and update each other's security policies through the interaction of information, which lays a foundation for the realization of self-healing network.

6. Conclusions

We proposed an ecological computer network model: Monomer-Multimer computer network model by introducing the knowledge of ecology into the field of computer network. This model is the first complete computer network model based on ecology. It can not only simulate the computer network, but also describe the dynamic development of computer network from the view of eco-development. The model can combine the theories of biology and computer networks to solve the security and survival issues of network. In addition, this model is easier to describe the information dissemination mechanism of the computer network. A variety of virus propagation models and anti-virus strategies can also apply to this model. In this paper, the proposed model is modeled and proved in detail. At the same time, the agent technology is used to simulate the model to verify its feasibility. The Monomer-Multimer computer network model is helpful to create a computer network with self-healing ability. It also provides ideas for the next generation computer network. At present, the study was only at the stage of simulation and the verification of concept. Further research work is mainly to apply the theoretical model to the practical research work and explore the deep-level simulation and analysis of the ecology network.

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